Real-time Sonification of Biceps Curl Exercise Using Muscular Activity and Kinematics

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ABSTRACT

In this research, we developed a real-time sonification system to be used in biceps curl. The sonification is generated using a parameter mapping method based on exercise information collected from a muscle sensor and Kinect camera. A cross-over trial (AB-BA method) using biceps curl exercises was conducted, which included 14 healthy subjects equally assigned to two different groups. The first group started their sessions without any feedback then received sonification in the last sessions. The other group completed the sessions with the sonic feedback in the early stages.

The experimental results show that the sonification worked well at portraying temporal information to help subjects improve the pacing of their movement. Results also show greater improvement in exercise metrics (greater average repetition range and total effort) when participants exercised with sonification, but not statistically significant. However, a significant result is that participants enjoyed the training more with the sonification than without. Positive comments were made on the sound feedback. The study demonstrates the potential for a real-time auditory feedback oriented training device to be used in fitness training or physical rehabilitation.

1. INTRODUCTION

1.1. Background

Sonification, as a means of portraying data using non-speech acoustic signals [1], has been applied in areas such as sport training and physical rehabilitation for many years. Typically, the output sounds are created based on a subject's body movement and bio-information. Biofeedback is used to provide an indication of the state of a bodily process using external sensors [2]. The purpose is to increase the awareness of a physiological response. In physical exercise, the use of biofeedback has the potential to improve the quality of exercise in many aspects, such as movement precision, temporal accuracy and muscular activity patterns [2].

Sound is a suitable candidate for portraying biofeedback due to several advantages [3]:

- The biofeedback is not restricted by a screen monitor, thus allowing visual attention to focus on the action or surroundings.
- Acoustic energy is very alerting and can be detected rapidly.
- Auditory information is superior to visual information in portraying time-sequenced (rhythmic) data.

For example, [4] developed auditory feedback of an ankle exercise, based on leg/foot ankle angle, which aimed to help visually impaired or bedridden patients improve the quality of physical rehabilitation. [5] is another example where the user's body movement was completely guided by sonification in sporting activity. Auditory biofeedback has also been applied to patients who lack proprioception as a means of improving the limb movement accuracy [6]. The use of biofeedback was also used in physical therapy related projects, such as the use of electromyography (EMG, a measurement of muscular activity) sonification in [7, 8].

The biceps curl is a highly popular training method, which involves both concentric contraction (lifting the dumbbell) and eccentric contraction (the lowering phase) of the key muscle. Yet many people do not pay enough attention to the *quality* of the exercise, for example lowering the dumbbell too quickly and skipping the effort of eccentric contraction. Therefore, this exercise is a good option with which to test the sonification device. This could also lead to applications in a wider range of physical exercise from fitness training to physical rehabilitation. Motor control can be improved through practice regardless of the complexity of the movement [9]. This assertion is highly important in physical exercise as better quality can contribute to quicker and greater improvement in body condition.

1.2. Research Overview

This study investigated whether the quality of physical exercise can be improved using real-time auditory feedback of users' exercise routines. In particular, we developed a sonification system facilitating sensory devices to measure a user's muscular activity and arm kinematics and mapped them into synthesis parameters for generating real-time auditory feedback. By listening to the feedback, we hypothesized that the users would be able to gain better awareness of their exercising states, which could potentially lead to a better exercise performance and progress. Another aspect we looked into was the general experience of using the sonification.

A cross-over trial was conducted to measure the effect of the sonification. In this method, equivalent groups of subjects receive counterbalanced sequences of each treatment, which cancels ordering effects and allows each subject to participate in all of the experimental manipulations [10, 11]. Specially, this experiment studied the effects of real-time auditory biofeedback in biceps curl exercise over an 8-session trial. Among the sessions, half of subjects were asked to do the exercise *without* the sonification for the first 4 sessions, then with the sonification for the other 4 sessions. The other half of the participants completed the same experiment but in the opposite fashion.

The experiment documented in this paper is a continuation of the previous between-subjects experiment

[12], which studied the effect of the sonification of biceps curls between two groups of participants in a 3-session setup. The between-subjects design could not avoid the individual differences of a participant's physical condition, which could influence the outcomes. The crossover experiment (within-subjects) eliminates the factor of individual differences. It was also performed over a longer scale than the previous experiment.

1.3. Paper Structure

Section 2 presents an overview of system design including descriptions of the sensory devices and the software platform. Section 3 provides details of the experiment, which consists of the experimental setup and procedures, and the quantitative/qualitative results. The summary section concludes the study and discusses the implications of the results.

2. SONIFICATION SYSTEM DESCRIPTION

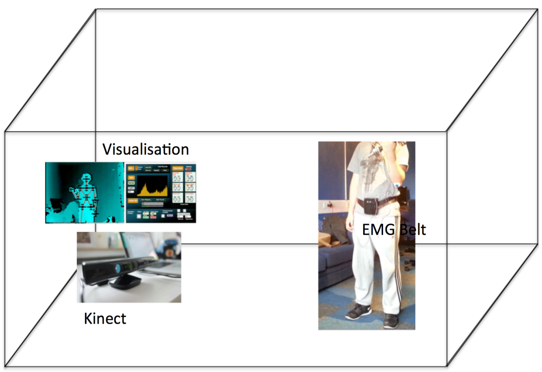

Figure 1: Setup example

A real-time sonification system was developed featuring an EMG (electromyogram) belt for muscular activity measurement and a Microsoft Kinect camera for limb position tracking. A software program was developed on Max/Msp to work with the sensory devices for generating the sonic feedback and data storage. A pictorial demonstration of the setup is shown in Figure 1.

The EMG belt consists of a surface EMG sensor for measuring myoelectric signals from the active muscle. The EMG signal is then transmitted to the computer (9600 baud) using an Arduino Duemilanove microprocessor with a Bluetooth modem.

The other sensory device, the Microsoft Kinect, is used to track the coordinates of a subject's arm relative to the centre of the torso. A program named *Synapse* [13] was used for tracking the movement, and coordinates of different body joints are then transmitted via Open Sound Control (OSC), which can be acquired directly in the sonification program.

The software environment is shown in Figure 2, which has three main functionalities:

(1) The *data management* section, also the main interface, consists of data visualization, data recorder, system setup and sound selection. The sampling rate for the data recorder is set at 50Hz, which is sufficient for recording the relatively slow biceps curl. Information being stored includes the EMG signal, hand coordinates, speed, repetition range. This section contains the basic analysis of the data, including calculating the rate of change of the y-coordinate of the hand (indicating the speed of biceps curl) and the range of repetition (difference between the lowest and highest y-coordinate of the hand).

(2) The *sound engine* used in this experiment is designed using frequency modulation and subtractive synthesis methods. As shown on the top right side of Figure 1, there are four different sound outputs for selection. However, this particular experiment only used the *Linear Synthesis Sound* option, which is different to our previously published experiment where participants were free to choose one of the four sounds according to their own preferences.

The linear synthesis sound produces a spectrally rich sound using two triangular oscillators. The pitch of the synthesizer varies continuously rather than using discrete MIDI signals. A band-pass filter is used to shape the brightness of the tone. Some users describe the overall tonal characteristic of this sound as "sci-fi". A white noise unit is used separately to function as a warning. This sound is triggered if the speed of movement is over a threshold value to encourage the user to exercise at a slower speed.

(3) The *data mapping* section links the bio-information to selected sound parameters, which were used to generate audio output. Parameter mapping [14] is used. We have chosen the EMG signal, y-coordinate of the active hand, movement velocity and repetition count as the input parameters. This data is scaled accordingly in order to create the correct range of values to control the sound parameters. Specifically, the pitch of the synthesizer is controlled by the active hand's y-coordinates and has a valid frequency range between 0 to 620Hz (from the lowest hand position to the highest). The EMG signal is mapped to control the cut-off frequency of the band-pass filter. As a result, the brightness of the sound is directly controlled by the biceps contractions (both concentric and eccentric). As more effort is exerted, the brighter the tone becomes. A white noise unit is also in use, which is controlled by the movement velocity. When the movement velocity is over a threshold value, the noise is triggered and heard by the user indicating that the user needs to slow down the pace of their exercise movement.

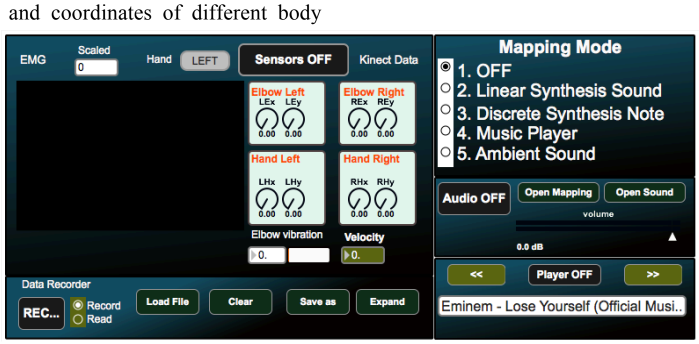

Figure 2: Main interface of the sonification software

3. EXPERIMENTS & ANALYSIS

3.1. Experimental Setup

This study was conducted to find out the difference in exercise quality between two phases for the same participant: effect phase and control phase. This means that all participants experienced doing biceps curl exercises both with and without the sonification feedback. The experiment was carried out at the Audio Lab in the Electronics Department, University of York, UK. 14 healthy university students participated in the experiment (8 females, 6 males, aged 24 ± 3). All participants were reported to be healthy with no conditions or injuries which could affect the exercise.

Participants were randomly assigned to two groups, referred to as *Con-son* (first four sessions **Con**ventionally without sound then the remaining four sessions with the **Son**ifcation) and *Son-con* (sonification first four sessions, then the remainder without). All participants signed a consent form prior to the first session, which explained the procedures and safety advice of the experiment. All participants completed the full 8-sessions of the experiment. There was 1-3 day's gap between each session to allow for the necessary muscle rest. Between the cross-over (before the fifth session), participants received a one week break with no heavy biceps-related training during this time.

Participants were advised that there were *three main criteria* in terms of the quality. Criterion 1 is to aim for a slow and steady pace, with each repetition to be completed in at least 4 seconds. Criterion 2 is to aim for a large range of motion of the lower arm, with the upper arm remaining static. Criterion 3 is to complete at least 2 sets of a minimum of 5 repetitions in one session. Participants were not encouraged to do as many repetitions as possible even though it was desired. This was to allow the participants to manage the quantity of exercise at their own motivation. However, being able to perform more repetitions is also an indication of good performance. The exercise and any safety issues were demonstrated to all participants prior to them commencing.

3.2. Quantitative Results

3.2.1. Repetition Time

The repetition time is the average time in seconds to complete one repetition of the biceps curl. Figure 3 presents the average repetition time in the two different treatments. Each data point is the overall average repetition time of that participant in the 4 sessions with the same treatment. The data is arranged according to participant's group.

Greater repetition time indicates slower movement velocity, which also indicates better exercise quality. Apart from participants 2 and 7, there were better results in the sonification phase (triangle) than the control phase (circle). Also, notice that the repetition times for participant 2 and 7 are very large already (No. 2: 7.9s in Sonification and 9.8s in Control; No7: 11.5s in Sonification and 11.95s in Control), which means that there was very little room for improvement.

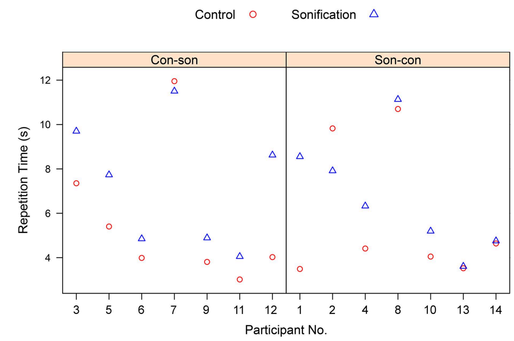

Figure 3: Average repetition time

A paired T-test was conducted, which indicated a significant difference between the mean value in the sonification phase (M = 7.06s, SD = 2.62) and the control phase (M = 5.73, SD = 2.98); $t(13) = 2.68$, $p < 0.05$. This indicates that the sonification worked very well at providing extra awareness to help participants to exercise at a slower pace (Criterion 1).

3.2.2. Repetition Range

The repetition range is the relative distance completed per repetition. The vertical hand coordinate (modified from the Kinect sensor) ranges between 0 (straight-arm position) and 0.8 (shoulder position) and 1 (top of the head). Figure 4 shows the comparison of the average repetition range of the participants based on the two different treatments. 9 out of 14 participants showed better results in the sonification phase.

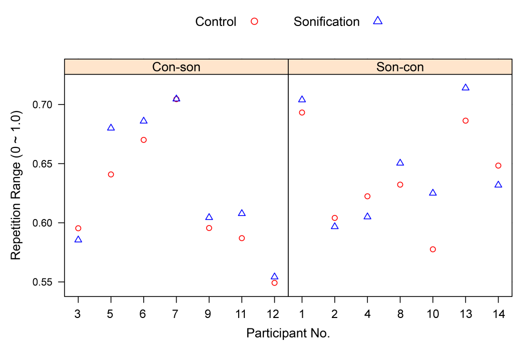

Figure 4: Average repetition range

No significant improvement was found in this variable between Sonification phase (M = 0.639, SD = 0.051) and Control phase (M = 0.629, SD = 0.047). However the significance level ($p = 0.076$) indicates the result is not far from being significant (0.05). This could be due to the relatively low difficulty of the exercise; most participants were already capable of achieving a good range of movement. Also, the relatively small sample size could affect the significance level.

3.2.3. Total effort

Total effort is defined as the product of dumbbell weight and the total repetition amount. This is because subjects were allowed to increase or decrease the selected dumbbell weight between sessions. If the weight is increased, achieving the same repetitions becomes more difficult.

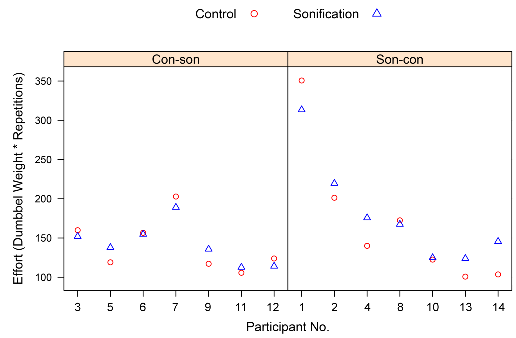

Figure 5: Effort comparison

The comparative result is shown in Figure 5. Paired T-test showed no significant difference ($p > 0.5$) in the effort results between the Sonification phase (M = 162, SD = 53) and Control phase (M = 155, SD = 66) even though the sonification phase has a higher recorded mean effort. However, some participants in the Son-con group expressed that after the sound was taken out, the exercise became more tedious to complete (No. 1, 4, 13, 14). Also, participant 1 said that while it had become less interesting without the sound, his muscle was already feeling stronger and hence he could still manage to finish more repetitions than in the initial sessions. In the Con-son group (adding the sound feedback from the fifth session), 3 participants showed improvement in the sonification phase; 3 have shown a decrease in effort and, 1 remained unchanged.

3.3. Survey Results

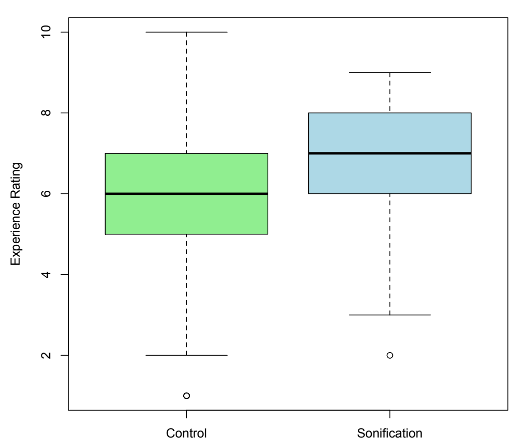

Figure 6: Boxplot of the user rating comparison

Participants were asked after each session to rate how much they enjoyed the workout after the exercise on a scale from 0 (not at all) to 10 (very enjoyable). Figure 6 shows that subjects in general had a more enjoyable experience when exercising with the sound feedback than without. A paired t-test was conducted to compare the mean rating for the two treatments. There is a significant difference in the rating for sonification (M = 6.93, SD = 1.57) and control (M = 5.73, SD = 2.28); $t(55) = 3.89$, $p < 0.001$.

Subjects were also asked to rate, on a scale of 0 (confusing) to 10 (informative), whether the sound gave sufficient feedback to the exercise movement. The mean value for this variable is M = 7.16, SD = 1.94, which indicates that the feedback was relatively informative to the majority of subjects. Regarding the sound aesthetic rating (0 being disliked to 10 highly enjoyable), the result is M = 6.30, SD = 1.86. The paired t-test shows a significant result of $t(55) = 3.87$, $p < 0.001$. A strong p value suggests that participants enjoyed the exercised more with the sonic feedback presented.

In addition, there was an optional question in the survey to let participants make open comments on the sessions. Selected results are shown in Table 1. Other results, which were mainly based on participant's physical condition after the session such as "feeling tired", have been excluded.

Type	Comment
Sound feedback	Paid attention to the sound. Aimed for a slower pace based on the sound. Able to get a smoother sound. Became more interesting (than without sound). Getting a steady sound. Exercise frequency affected by the sound.
Without feedback	Boring. Not as fun. Exercise felt more difficult than with the sound
By the end of the sessions	Feeling stronger Exercise became easier

Table 1: Subjects' open comments

Overall, participants made positive comments on the sound feedback, which mainly focused on how the sound feedback can affect the pacing of movement and make exercise more interesting. Similarly, three participants in the Son-con group felt the sessions had become less interesting after the sound feedback had been removed.

4. ANALYSIS

The three main conclusions that can be drawn from these experiments are as follows:

1. The sonic feedback has a strong impact on the pacing of the movement. There is not enough support to indicate the auditory feedback could lead to a larger repetition range. Although no obvious improvement is shown in the total effort, the post-session survey indicated that participants felt more motivated with the auditory feedback.

2. A significant result is shown that the participants enjoyed the exercise more with the feedback than without.

3. Participants generally found the auditory feedback informative. However, the sound aesthetic still has room for improvement. While this particular experiment used only one type of sound for the sonification, the system provides other options such as probability-based melodic mode, sea wave sounds, and a music player allowing users to upload their own music files. Hence, there are more options to accommodate a user's personal preference.

5. SUMMARY

This paper presented a study of the effect of real-time sonification on a subject's biceps curl exercise based on muscular activity and movement information. A sonification system was developed, which consisted of an EMG sensor belt and a Microsoft Kinect camera as hardware, and custom sonification software using Max/Msp. A cross-over trial was conducted to study the difference in exercise quality between 2 phases (exercise with auditory biofeedback and without auditory biofeedback) in 2 different sequences.

The experimental results resonate with the previous experiment we conducted based on fixed treatment group comparisons. This latest study shows that participants performed better with sonification in terms of pacing, but no significant difference was seen in movement range. This result indicates that the auditory feedback is more effective at portraying the temporal characteristic of the movement. Also, participants found exercising with the sound more motivating and interesting. This is an important finding, especially as a repetitive exercise over a longer time scale is often considered to be tedious. According to participant feedback, the sound was considered to be informative.

A conclusion is drawn concerning the movement range mapping. The movement range was portrayed with a linear mapping of the pitch of the synthesis. The continuous mapping could provide a raw portrayal of the hand's position yet is not suggestive enough for the listener to realise the quality of that variable. Further adjustment is required to make this mapping more intuitive. A possible approach is to use notification to sonically present whether the movement range is considered as 'good' or 'bad' quality rather than the current raw representation.

In summary, the sonification used in this research does not only relate to the biceps curl itself, but also shows that the auditory cue could help the users to regulate their action in order to satisfy certain exercise criteria. The sonification has the potential to improve the quality of physical exercise and the current system can be developed further to suit more exercise types. This has applications both in fitness training and physical rehabilitation. In comparison to some of the commercial products such as Wii Sports and Xbox games, this system places more attention on portraying the user's muscular activity, which is an essential attribute in weight training. In addition, the exclusive use of sonic display has possibilities for multitasking and portability.

One of the possible further developments of this system involvement is to replace the Kinect camera with an accelerometer to detect movement velocity. By doing so, the system can be developed as a wearable device, which has greater accessibility for situations such as outdoor physical activity. In recent years, we have experienced a revolution of portable computing device and wearable technology. Products such as smartphones, smartwatches and fitness tracking gadgets provide sonification designers with a huge worldwide platform for developing auditory assistive tools and devices to help to improve our general health. As more situations are made possible to extract biodata, auditory biofeedback has the advantage of being screen-free and interesting to use, while delivering sufficient bio-information to increase the awareness of the exercise. With more advanced sensory devices becoming available to the public and the advantage of the mobile application market, the next stage for the research is to implement the sonification into mobile platforms, which could hence improve the portability and accessibility.

6. ACKNOWLEDGMENT

We would like to express our sincere gratitude to all the people who took part in the experiment.

7. REFERENCES

[1] T. Hermann, A. Hunt and J. G. Neuhoff, *The Sonification Handbook,* Logos Verlag, 2011.

[2] G. E. Schwartz and J. Beatty, *Biofeedback Theory and Research,* Academic Press, 1977.

[3] G. Kramer, *Auditory display, sonification, audification, and auditory interfaces,* Addison Wesley, pp. 6-8, 1994.

[4] M. Matsubara, H. Kadone, M. Iguchi, H. Terasawa and K. Suzuki, *The effectiveness of auditory biofeedback on a tracking task for ankle joint movements in rehabilitation,* Proceedings of 4th Interactive Sonification Workshop (ISON), 2013.

[5] T. Hermann, O. Höner and H. Ritter, *Acoumotion – an interactive sonification system for acoustic motion control,* Gesture in Human-Computer Interaction and Simulation, pp. 312-323, 2006.

[6] C. Ghez, T. Rikakis, R. L. DuBois and P. R. Cook, *An auditory display system for aiding interjoint coordination,* Proceedings of the International Conference on Auditory Display, 2000.

[7] S. Pauletto and A. Hunt, *The sonification of EMG data,* Proceedings of the 12th International Conference on Auditory Display, 2006.

[8] R. V. Croce *The effect of EMG biofeedback on strength acquisition,* Biofeedback and self regulation, vol. 11, no. 4, 1986.

[9] G. L. Gottlieb, D. M. Corcos, S. Jaric and G. C. Agarwal, *Practice improves even the simplest movement,* Experimental Brain Research, vol. 73, pp. 436-440, 1988.

[10] M. Bland, *Cross-over trials,* [Online], Available: http://www-users.york.ac.uk/~mb55/msc/trials/cross.htm, Sep 2010.

[11] S. Senn, *Cross-over trials in clinical research,* John Wiley & Sons, 2002.

[12] J. Yang and A. Hunt, *Real-Time Auditory Feedback of Arm Movement and EMG in Biceps Curl Training to Enhance the Quality,* Proceedings of SoniHED – Conference on Sonification of Health and Environmental Data, 2014.

[13] http://synapsekinect.tumblr.com/post/6307752257/maxmsp-jitter

[14] T. Hermann, *Taxonomy and Definitions for Sonification and Auditory Display,* Proceedings of 14th International Conference on Auditory Display, France: IRCAM, 2008